

CASA-BLANCA: A LARGE NON-IMAGING CERENKOV DETECTOR AT CASA-MIA

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ABSTRACT

The lateral distribution of Cerenkov light at ground level records important information on the development of the air shower which produces it. We have constructed a Broad Lateral Non-imaging Cerenkov Array (BLANCA) to measure this lateral distribution at the CASA-MIA air shower detector in Dugway, Utah. Together, the arrays can sample the lateral distributions of electrons, muons, and Cerenkov light, at many well-measured distances from the shower core. We describe the design and calibration of the CASA-BLANCA experiment and its ability to address the composition of primary cosmic rays between 3×10^{14} and 3×10^{16} eV.

INTRODUCTION

Ground-based measurements of the cosmic ray energy spectrum show a clear break in the vicinity of 3×10^{15} eV, known as the spectral “knee.” Over a range of several decades lower in energy, the spectrum falls as $E^{-2.7}$; at higher energies, the power law index steepens to ~ 3.15 (Gaisser et al., 1995). This change in slope is not understood. The favored supernova shock wave model for cosmic ray acceleration does give rise to a natural cut-off in energy, due to the limited duration of the supernove explosion, but it fails to explain the spectrum above that cut-off (Drury et al., 1994). The elemental composition of cosmic rays can provide clues to this problem, because both the processes of shock acceleration and escape from the galaxy depend on the magnetic rigidity of the particle. Any cut-off energy should be higher for particles with greater charge, hence a heavier composition above the knee. Speculations of high energy cosmic rays coming from extra-galactic sources, however, lead to predictions of progressively lighter composition at higher energy (Protheroe and Szabo, 1992). Unfortunately, given the low cosmic ray flux at high energies, direct measurements of the composition at and above the knee are not now possible.

Since a ground-based cosmic ray experiment does not directly observe the parameters of astrophysical interest—cosmic ray energy and nuclear charge—it must instead measure as many complementary properties of the air shower as possible. The lateral distribution of Cerenkov light about the core of the shower is one such property. Air shower simulations show that more than ~ 150 m from the shower core, the density of Cerenkov light is quite insensitive to the primary cosmic ray species

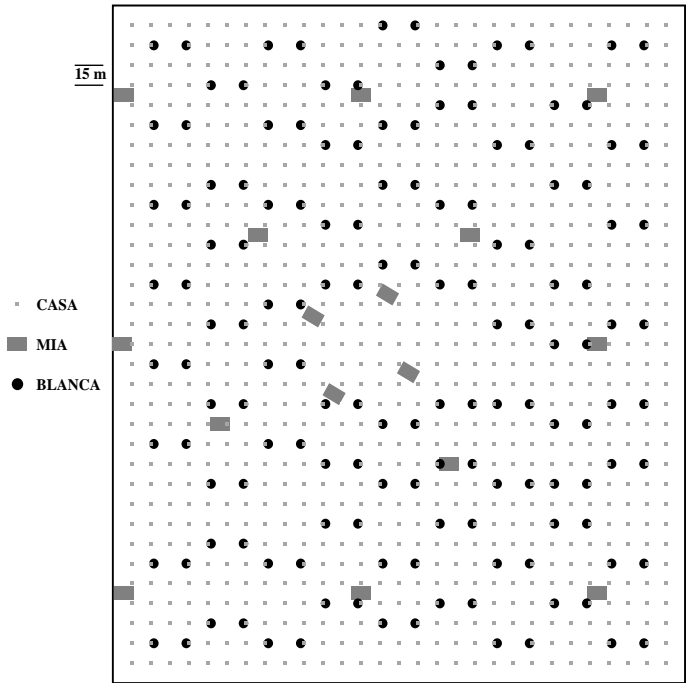


Fig. 1: The CASA-MIA and BLANCA detector arrays.

the core is much more sensitive to the penetration depth of the shower into the atmosphere, which in turn correlates closely with the mass of the primary particle: lighter nuclei penetrate more deeply. We have constructed the BLANCA array to sample the Cerenkov light distribution. Other important shower properties are also measured at the same site, including the number and distribution of muons and electromagnetic particles.

THE CASA-MIA INSTRUMENT

The CASA-MIA experiment, located in Dugway, Utah, U.S.A. (40.2° N, 112.8° W), consists of a surface array (CASA) of 1089 scintillation detector stations and a muon array (MIA) of 1024 scintillation counters (Borione et al., 1994). The general arrangement is shown in Figure 1. Buried three meters underground in sixteen patches, the muon counters have a total active area of 2500 m^2 . The surface array now operates with only 885 stations, enclosing an area of $2.0 \times 10^5 \text{ m}^2$. Each surface station has 1.3 m^2 of scintillator area. The location of air shower cores is determined by finding the point of maximum surface particle density, and shower arrival directions are reconstructed using surface detector timing information. For cosmic rays of interest here—*i.e.* above 300 TeV—the core uncertainty is ~ 3 meters, and the angular resolution is less than 1° . CASA-MIA has been in continuous operation since January, 1992.

To the existing CASA-MIA experiment, we have added 144 non-imaging Cerenkov light detectors. These detectors are arrayed as show in Figure 1, with a typical spacing of ~ 35 m. The BLANCA array has no trigger mechanism of its own. Instead, the detector pairs decide locally whether to record data each time the CASA surface array triggers. Since the estimated threshold energy at CASA even for heavy nuclei is below 300 TeV, this method is fully efficient at capturing the high energy showers sought by BLANCA.

BLANCA CERENKOV DETECTORS

The BLANCA units each contain a large Winston cone, concentrating light on a 3-inch photomultiplier tube (Figure 2). The cone is oriented vertically and has a nominal acceptance half-angle of 12.5° . It is made of clear plastic, aluminized on its inner surface through vacuum deposition. The PMT is placed in a magnetically shielded housing, with its window as close as possible to the output aperture of the cone. However, a rotating shutter is placed between them to protect the photocathode from sunlight. At night, a motor can be commanded remotely to rotate this shutter into its open position. A two-gain pre-amplifier mounted near the tube housing amplifies the PMT pulses by factors of 40 and 1.5. The second (low-gain) channel alleviates the dynamic range restrictions that would otherwise result from ADC saturation on the high-gain channel. When combined, these two outputs give BLANCA sensitivity to Cerenkov light signals varying over three orders of magnitude. Both pre-amp outputs are connected to a modified CASA station board 15 meters away. In this configuration, the four QDC channels on a single board can serve two BLANCA units, hence the paired geometry seen in Figure 1. The same board controls the shutter operations and the high voltage supplied to the detector pair. For protection from the elements, the BLANCA units fit into PVC enclosures 37 cm in diameter. An equally large piece of UV-transmitting glass sealed to

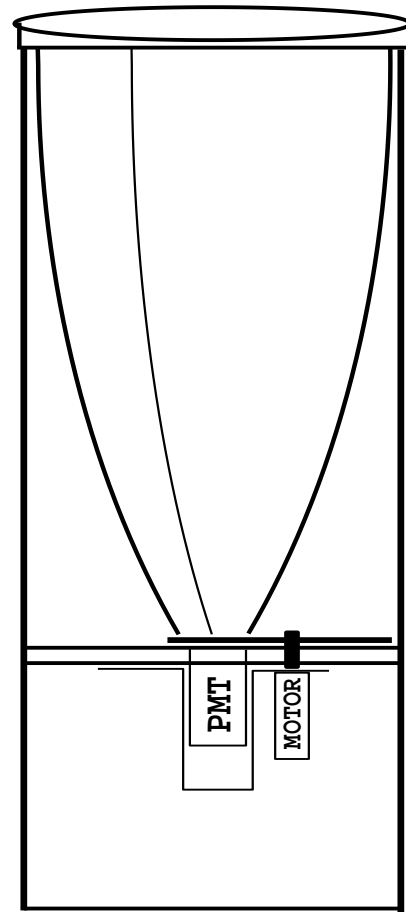


Fig. 2: A BLANCA detector.

Average spacing	35 m
Overall enclosed area	201,600 m ²
Cone half-angle	12.5°
Cone size	Length: 61 cm Entrance Diam: 36 cm Exit diam: 7.6 cm
PMT diameter	8.3 cm

Table 1: *Physical characteristics of BLANCA and its detector units.*

the top of each Winston cone keeps rain and moisture out of the entire assembly. Finally, an 8-Watt heater wire warms the glass to melt snow and eliminate frost.

The Winston cone used in each BLANCA serves both as a collimator—substantially reducing night sky background light—and a concentrator. These cones were manufactured based on the exact form of a Winston cone with acceptance half-angle of 12.5° and exit aperture having 90% the diameter of our PMTs. Such an optical element would transmit almost all light arriving inside its acceptance cone and reflect almost all light outside it (Welford and Winston, 1989). However, the BLANCA cone was truncated to only 61 cm, or 63% of the ideal length. This alteration reduces the collecting area from 970 cm² to 880 cm² and also compromises the collimating effect somewhat. The necessity of placing protective shutters between the cones and PMTs effectively reduces the cones' acceptance angle to roughly 11°. Figure 3 shows the transmission of ideal and more realistic cones as a function of entrance angle, calculated with ray-tracing algorithms.

The 10-stage EMI photomultiplier tubes used in BLANCA were each calibrated at the University of Utah before installation. The calibration system used a continuous beam helium-cadmium laser (325 nm) with constant and known intensity, measuring the tube anode current at four different voltages. We used these results to operate all BLANCA tubes in the array as nearly as possible at the same gain. We also had four typical PMTs tested by Philips to confirm that all had similar cathode sensitivities between 300 and 500 nm.

The full array of 144 BLANCA detectors was constructed and installed at the Dugway site between July, 1996 and January, 1997. From its completion to mid-May, 1997, CASA-BLANCA has recorded 200 hours of Cerenkov data. Using the Akeno measurement of the cosmic ray spectrum (Gaisser et al., 1995), we estimate that this data sample contains 4000 air showers above 2×10^{15} eV and 170 above 10^{16} eV. With anticipated running in the winter of 1998, we hope at least to double this data set.

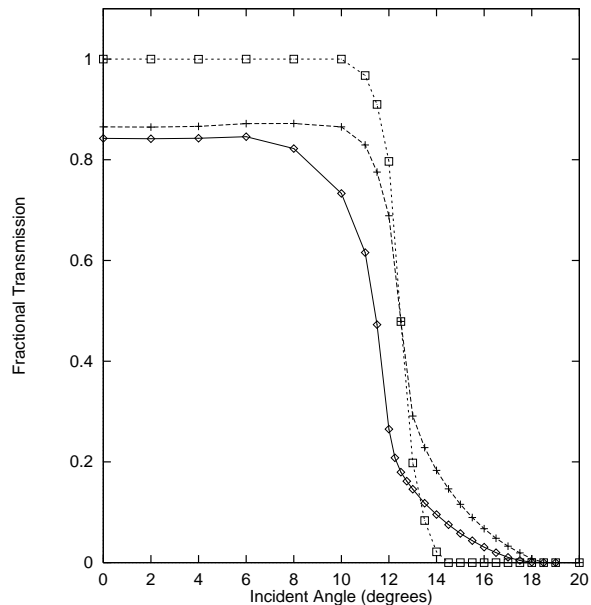


Fig. 3: *Fraction of collimated light entering the Winston cone which is transmitted to the PMT face, as a function of entrance angle. The dotted curve represents an ideal 12.5° cone; the dashed curve assumes a 90% mirror reflectivity and cone truncation at 61 cm length; the solid curve also adds the effect of the 6 mm gap between BLANCA cones and the phototubes.*

Converting observed ADC values into Cerenkov light density measurements requires a calibration of the sensitivity of each BLANCA detector. We consider the independent performance of the elements separately to get a first estimate of this sensitivity. Combining the optical properties of the glass top and the cone, the lab results on the PMT gains, and studies of the pre-amp and digitizing circuit, we estimate that one ADC count corresponds to about 0.1 blue Cerenkov photons per cm^2 above the glass detector lids. BLANCA should be able to measure Cerenkov photon densities roughly between $1\text{--}2\text{ cm}^{-2}$ and 3000 cm^{-2} . Night sky background light and electronic noise limit the lowest accessible density; ADC saturation even on the low-gain pre-amplifier output limits measurements of very high photon densities.

On a nightly basis, the relative sensitivities of the BLANCA stations can be found from the Cerenkov data themselves. This procedure relies only on the uniform distribution of air shower cores over the array, which can be checked using CASA alone. We also expect to monitor time variations of the PMT and amplifier gains using shower Cerenkov light, under the assumption that the energy spectrum of Cosmic ray showers is steady from night to night.

With these methods of finding the relative sensitivities between tubes and between observing periods, the question remains how to find the absolute response of the array to Cerenkov light. We have begun to develop a portable flasher incorporating a blue LED and collimating optics which can be carried to several BLANCA detectors in one night. The LED light pulse output would be determined by flashing a calibrated PMT. Also, BLANCA has recorded flashes of light from the HiRes Laserscope (Bird, 1996)—a nitrogen laser aimed horizontally 150 m above the entire BLANCA array. Since the amount of light scattered into a detector depends only on the elevation angle of the laser path as seen by that detector, these data can provide an external check on the accuracy of our relative calibrations. Calculations of the amount of scattered laser light will also help to establish the absolute detector sensitivities.

CONCLUSIONS

The main strength of the CASA-BLANCA experiment is its ability to measure multiple components of incident air showers. BLANCA itself, with 144 separate stations, insures several Cerenkov light density samples near a shower core. By measuring this density and other shower parameters simultaneously, we will vastly improve our ability to determine the cosmic ray composition at the knee.

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